REVIEW OF TECHNICAL STUDIES IN THE UNITED STATES IN SUPPORT OF BURNUP CREDIT REGULATORY GUIDANCE FOR TRANSPORT

John Wagner, Cecil Parks, Don Mueller, Ian Gauld
Oak Ridge National Laboratory

International Workshop on Advances in Applications of Burnup Credit for Spent Fuel Storage, Transport, Reprocessing, and Disposition

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Introduction

• Interest in burnup credit has motivated numerous technical studies, domestically and internationally.

• The number of countries interested in burnup credit increases each year.

• The purpose of this presentation/paper is to draw attention to existing publications that may be useful to people entering the field of burnup credit.
Introduction

- In 1999, the US NRC initiated a research program with ORNL to develop guidance and technical bases for allowing and expanding the use of burnup credit in PWR SNF storage and transport applications.

- The research program attempted to systematically address technical issues in the pursuit of expanding regulatory guidance for the use of burnup credit.

- The program produced a number of reports that are publically available.
Baseline Report, 1999

- Reviewed application areas
- Reviewed previous technical studies
- Reviewed/identified parameters/phenomenon
- Reviewed technical and licensing issues
- Proposed research and prioritization
- Status of burnup credit programs in other countries
Reactivity Equivalencing, 2000

• Investigated the practice of equating the reactivity of spent fuel to the reactivity of fresh fuel, referred to as reactivity equivalencing for PWR SFP conditions

• Looked at normal and accident conditions, as well as various storage configurations

• Demonstrated practice to be acceptable, when used properly

• Demonstrated inaccurate and non-conservative reactivity estimates when used improperly
Computational Benchmark, 2001

- Defined representative high-capacity cask
- Estimated additional reactivity margin available from fission products and minor actinides, per ISG-8 recommendation

Table 15 Individual components of the reduction in $k_{eff}$ as a function of burnup and cooling time for fuel of 5 wt % U enrichment

<table>
<thead>
<tr>
<th>Burnup (GWD/MTU)</th>
<th>$\Delta k$ due to various nuclide sets</th>
<th>Contribution to total reduction in $k_{eff}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Major actinides (set 1)</td>
<td>Additional nuclides (set 3)</td>
</tr>
<tr>
<td>0-year cooling time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.04286</td>
<td>0.03563</td>
</tr>
<tr>
<td>20</td>
<td>0.08854</td>
<td>0.05156</td>
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<tr>
<td>30</td>
<td>0.12911</td>
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<td>40</td>
<td>0.16453</td>
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<td>50</td>
<td>0.19746</td>
<td>0.07552</td>
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<tr>
<td>60</td>
<td>0.22739</td>
<td>0.08263</td>
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<tr>
<td>5-year cooling time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.04334</td>
<td>0.04838</td>
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<tr>
<td>20</td>
<td>0.09339</td>
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<td>0.08761</td>
</tr>
<tr>
<td>60</td>
<td>0.24198</td>
<td>0.09595</td>
</tr>
</tbody>
</table>
SCALE BUC Sequence, 2001

- STARBUCS sequence to automate burnup credit analyses for UO$_2$ SNF systems
- Performs integrated depletion analysis, cross-section processing, and Monte Carlo calculations for 3-D systems
- Relevant input options to represent
  - Irradiation conditions
  - Cooling time
  - Nuclides relevant to burnup credit
  - Axial and radial variation of burnup
  - Isotopic composition uncertainties
- Used extensively at ORNL to study burnup credit issues

See presentation this afternoon for latest developments: “Enhancements to the Burnup Credit Criticality Safety Analysis Sequence in SCALE”, Radulescu and Gauld

NUREG/CR-6748
Burnable Poison Rods, 2002

• Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions

BPR Exposure Cases

- 24 WABA present for 3 cycles
- 24 WABA present for 1 cycle
- 24 WABA present for 2 cycles
- 12 WABA present for 3 cycles

Lower-right quadrant of W17x17 assembly with 24 WABA rods present

BPR Burnup Exposure

- Total Burnup = 45 GWd/MTU for all cases

NUREG/CR-6761

Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions.
Integral Burnable Absorbers, 2002

- Investigated effect of IBAs on reactivity, ZrB$_2$, UO$_2$-Gd$_2$O$_3$, UO$_2$-Er$_2$O$_3$, Al$_2$O$_3$-B$_4$C

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**Graph:**

- **Y-axis:** $k_{inf}$
- **X-axis:** Burnup [GWd/MTU]
- **Legend:**
  - no IFBA
  - 32 IFBA
  - 64 IFBA
  - 80 IFBA
  - 104 IFBA
  - 128 IFBA
  - 156 IFBA

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**Graph:**

- **Y-axis:** $\Delta k$ [k(IFBA) - k(no_IFBA)]
- **X-axis:** Burnup [GWd/MTU]
- **Legend:**
  - 32 IFBA
  - 64 IFBA
  - 80 IFBA
  - 104 IFBA
  - 128 IFBA
  - 156 IFBA

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**Graph:**

- **Y-axis:** $\Delta k$ [k(Gd$_2$O$_3$) - k(no_Gd$_2$O$_3$)]
- **X-axis:** Burnup [GWd/MTU]
- **Legend:**
  - S1
  - S2
  - S3
  - S4

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**Graph:**

- **Y-axis:** $\Delta k$ [k(UO$_2$-Gd$_2$O$_3$)]
- **X-axis:** Burnup [GWd/MTU]
- **Legend:**
  - S1
  - S2
  - S3
  - S4
Control Rods, 2002

- Investigated effect of CRs on reactivity for CR/APSR designs & exposure conditions

- W, B&W, and CE designs considered

![Graphs showing reactivity changes with burnup and axial depth of CR insertion]

CRs removed at 5 GWd/MTU
CRs removed at 15 GWd/MTU
CRs removed at 30 GWd/MTU
CRs present during entire depletion

NUREG/CR-6759

Parametric Study of the Effect of Control Rods for PWR Burnup Credit

Prepared by
U. S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Oak Ridge National Laboratory

3.0 wt% U-235
4.0 wt% U-235
5.0 wt% U-235

Burnup [GWd/MTU]

Axial depth of CR insertion (distance from top of active fuel, cm)
Cooling Time, 2003

- Examined reactivity behavior as a function of cooling time to assess the possibility of modifying guidance recommendation.

![Graph showing reactivity behavior as a function of cooling time.](image-url)

- Increase in reactivity due to decay of short-lived fission products.
- Decrease in reactivity after $^{241}$Am & $^{240}$Pu decay completes and $^{239}$Pu decay dominates.
- Increase in reactivity due to decay of $^{241}$Am ($t_{1/2}=433$y) and $^{240}$Pu ($t_{1/2}=6560$y).
- Decrease in reactivity due to decay of $^{241}$Pu ($t_{1/2}=14.4$y) and buildup of $^{241}$Am and $^{155}$Gd (from $^{155}$Eu, $t_{1/2}=4.7$y).
Axial Burnup, 2003

- Examined effect of axial burnup on reactivity
- Examined available database of profiles to
  - identify profiles that maximize, $k_{eff}$,
  - assess its adequacy for use in safety analyses
  - investigate the existence of trends with fuel type and/or reactor operations
Reactivity Margins, 2003

- Examined impact of depletion & criticality analysis assumptions on loading curves
Reactivity Margins, (cont’d)

- Quantified large impact of ICFs
- Confirmed need for FP credit

US PWR discharge data through 1998

**Graph:**
- **Reference Case (ISG-8r2) (9% acceptable)**
- **Primary 6 Fission Products, Isotope Correction Factors (38%)**
- **Primary 6 Fission Products, Best Estimate Bias & Uncertainty (78%)**
- **16 Fission Products, Best Estimate Bias & Uncertainty (90%)**
- **16 Fission Products, No Bias or Uncertainty (98%)**
Isotopic Validation, 2003

- Examined strategies for addressing uncertainties in predicted isotopic comps.
  - Reviewed/applied methods and data
    - Bounding methods
    - Best estimate methods
      - Monte Carlo sampling
      - Sensitivity coefficient analysis
      - Direct isotopic differencing

\[ ^{155}\text{Eu} \]

- Examined strategies for addressing uncertainties in predicted isotopic comps.

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\[ ^{155}\text{Eu} \]
Applicability of CRCs, 2008

- Examined neutronic similarities between a SNF cask and 40 CRC state-points

CRCs found to be good in terms of applicability; how to address uncertainties?
Assembly Misloading, 2008

- Examined effect of fuel misloading on $k_{\text{eff}}$
- A variety of fuel-misloading configurations were investigated to understand impact

\[\Delta k\] effect of misloading a single fresh assembly with 5 wt\% $^{235}$U enrichment in different locations within the GBC-32 cask

Effect of systematic error in burnup for all 32 assemblies

NUREG/CR-6955
Criticality Validation–HTC data

- Examined applicability/usefulness of French critical experiments (Valduc) for actinide validation
  - 156 configurations with designed to mimic 4.5 wt% $^{235}$U initial enrichment fuel burned to 37.5 GWd/MTU in storage & transport conditions
Burnup Confirmation

• Provides information and issues relevant to pre-shipment burnup measurements when using burnup credit in PWR SNF storage & transport casks

• The report provides a review of:
  – the role of burnup measurements in the regulatory guidance (ISG-8) for demonstrating compliance with burnup loading criteria
  – burnup measurement capabilities and experience
  – accuracy of utility burnup records
  – fuel movement and misloading experience
  – the consequences of misloading assemblies in casks designed for burnup credit

• The report also provides observations based on the review

• Report being finalized
Current Focus Area – FP Validation

- Methods and data for criticality validation with FPs
  - See Don Mueller’s presentation Wednesday PM

- Methods and data for isotopic validation with FPs
  - See Ian Gauld’s presentation on Wednesday PM
Other Technical Resources

• OECD/NEA Expert Group publications
• Meeting proceedings and journal articles
• Technical reports from US DOE and other organizations
• Regulatory guidance/standards from safety authorities
• ANSI/ANS-8.27-2008: Burnup Credit for LWR Fuel

• Burnup credit bibliographies:
Concluding Remarks

• US NRC initiated and maintained a research program to address burnup credit technical issues with the goal of allowing and expanding the use of burnup credit in PWR SNF storage and transport applications

• A great deal of work has been performed by ORNL and others in the US and abroad, particularly for PWR SNF

• Hopefully this work is and will be useful to others for
  – Learning and understanding issues
  – Reducing redundant work, thereby enabling focused efforts on remaining important technical issues
Current and Expected Future Activities

- Methods and approaches for FP validation
- BWR burnup credit